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ON THE RELATION BETWEEN THE ICE TRANSPORT IN THE EAST GREENLAND CURRENT AND THE ATMOSPHERIC CIRCULATION OVER THE ARCTIC OCEAN

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The ice drift in the Arctic Ocean is largely influenced by the atmospheric circulation. But, on the other hand, the ice drift itself affects the ice transport in the East Greenland Current, which mainly transports sea ice from the Arctic Ocean to the South. Thus, some kind of relationship between the atmospheric circulation over the Arctic Ocean and the carriage of ice by the East Greenland Current can be assumed. The ice conditions in the East Greenland Current are described by the mean expansion of the ice belt between 65°N and 70°N during the months of April through August. Compared with the long-term

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20. Abstract (cont'd)

mean, the years 1949-52 proved to have been rich in ice, the years 1957-58 poor in ice. The pattern of the atmospheric circulation over the Arctic Ocean was derived from differences in the atmospheric pressure between the terminal points of the following two profiles: Profile A--on the 180th meridian between $85^{o}N$ and $75^{o}N$, and Profile B--on $80^{o}E$ between the North Pole and $80^{o}N$. A comparison of single values corresponding in time suggests that the years with a $\frac{\text{greater}}{\text{smaller}}$ amount of ice carried by the East Greenland Current will have been preceded by a wind-produced influx of ice $\frac{\text{from}}{\text{into}}$ the region of the Pacific Gyral $\frac{\text{into}}{\text{from}}$ the area of the $\frac{\text{strongly}}{\text{weakly}}$ developed Transpolar Drift Stream. The same statement can be derived from the varying frequency of distinct types of atmospheric circulation during the two quadrennial periods investigated. The results obtained suggest that the above reflections might be worth considering in a long-term forecast of the ice masses carried by the East Greenland Current.

Deutsche Hydrographische Zeitschrift
Vol. 20, No. 6, 1967

ON THE RELATION BETWEEN THE ICE TRANSPORT IN THE EAST GREENLAND CURRENT AND THE ATMOSPHERIC CIRCULATION OVER THE ARCTIC OCEAN*

Klaus Strübing

INTRODUCTION: The present investigation is based on two fundamental facts.

1. The sea ice which drifts southward with the East Greenland Current is mainly created under the climatic conditions of the Arctic Ocean. In principle, the East Greenland Current functions only as a conveyor belt transporting foreign ice towards the south, whereby the quantity of the exported polar pack ice not only changes seasonally but also may show stronger fluctuations from year to year.

2. A definite pattern of the ice drift, consisting of two largely independent systems (See Figure 1) emerged from the research findings of the last two decades (Cf P.A. Gordienko [1958], F. Nusser [1960], M. Dunbar and W. Wittman [1963], N.A. Volkov and Z.M. Gudkovich [1967]). On the Eurasian side of the Arctic Ocean, north of the continental shelf, there is a straight line ice drift from approximately the area of the East Siberian Sea to the exit opening between Greenland and Spitzbergen. This so-called Transpolar Drift Current continues towards the south in the East Greenland Current. On the North American side, the polar pack ice drifts in an almost closed anticyclonal system, the so-called Pacific Gyral, mainly over the Canadian basin. With unidirectional ice drift, the two systems touch each other approximately over the Siberian basin of the Arctic Ocean, i.e. in the marine area between the Lomosov and the Alpha ridges.

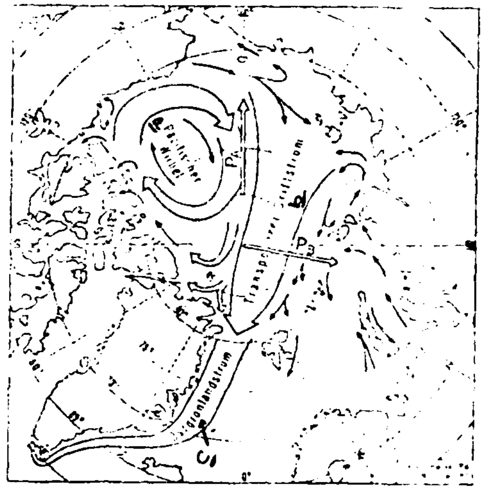


Figure 1: Pattern of the ice drift in the Arctic Ocean and the East Greenland Current. (a: Pacific Gyral; b: Transpolar Drift Current; c: East Greenland Current.)

Thus, in that marine area, a mutual influence of the two systems may occur due to localization changes of the atmospheric circulation centers by means of a wind-generated ice drift: an outflow of ice from the Pacific Gyral into the Transpolar Drift Current could then also increase the ice transport of the East Greenland Current due to generally increased and somewhat delayed ice transport; the opposite conditions could decrease the latter ice transport. Figure 2 a shows an example of this wind-generated transfer of ice from the Pacific Gyral into the Transpolar Drift Current. While the air pressure distribution in Figure 2 b corresponds to the ice drift pattern, the relocation of the high pressure center from the Canadian Basin to the Eurasian side of the Arctic Ocean causes an outflow of ice from the Pacific Gyral, which increases the ice transport of the Transpolar Drift Current.

*Based on a presentation given during the convention of Meteorologists and Geophysicists in Hamburg on April 2, 1968.

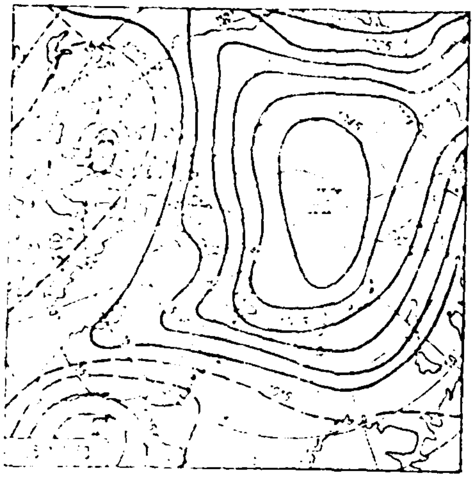
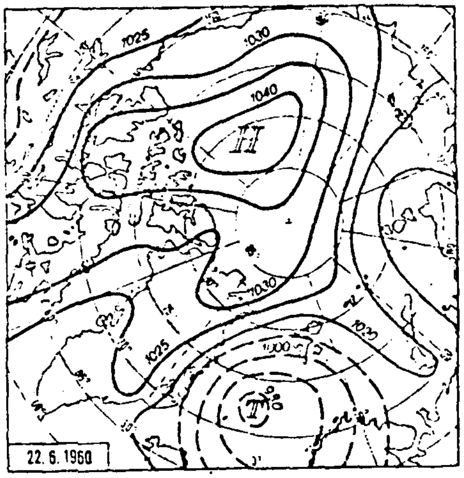


Figure 2 a: Air pressure distribution*) causing a wind-generated ice transport from the Pacific Gyral into the Transpolar Drift Current. [January 26, 1960]

Figure 2 b: Air pressure distribution conforming with the ice drift pattern. [June 22, 1960].



The present investigation is based on the assumption that the wind-generated ice exchange between the two drift systems occurs mainly in the area of the 180th meridian between 75°N and 85°N (See K. Strübing [1967]).

2. THE ICE TRANSPORT OF THE EAST GREENLAND CURRENT. Information concerning the ice conditions in the marine area east of Greenland has been published in the corresponding annals of the Danish Institute of Meteorology at Charlottenlund (see bibliography). Comparative studies over longer periods of time have hitherto been possible only by indications of the mean

*) The air pressure distributions presented in Figures 2 a, 2 b, 7, 8, and 9 refer to sections of the land weather maps of the dates indicated (German meteorological service [Deutscher Wetterdienst], daily weather forecasts).

expansion of the ice belt during the five months of April through August. It should also be pointed out, in this context, that there are certain shortcomings in the material due to the size of the marine area and the limited observation possibilities, primarily up to approximately 1959; however, these deficiencies cannot be treated in detail here. Nevertheless, the material appears sufficient for large scale and long-term investigations. (Only in most recent years, satellite photos have provided an observation aid which - as shown in Figures 3 a - 3 d - make it possible to e.g. establish the development of the ice edge within the East Greenland Current area at a specific time and to recognize and analyze its short-term fluctuations.)

The conditions in the section from 65°N to 70°N within the wider area of the Denmark Strait*) seem most suitable for a general characterization of the ice transport in the East Greenland Current, due to the observation material as well as the oceanographic and meteorological conditions. In this region, the mean expansion of the ice belt was defined during the months of April through August in the 24 years of 1931-39, 1946-58, 1960-61 as being 160,000 km^2. With a longitudinal expansion of approx. 1,100 km (565 nautical miles) the mean width of the ice belt can be calculated to approximately 145 km (80 nautical miles). In comparison with this 24-year mean, the years 1949-52 can be characterized as rich in ice, the years 1957-58 and 1960-61**) as poor. Figure 4 illustrates the deviations of the corresponding annual values from the 24-year mean. The maximum expansion of the ice was 220,000 km^2 (1952), the minimum expanse 90,000 km^2 (1957). The mean of the ice-rich period is a 194,000 km^2; a value of 121,000 km^2 represents the mean of the ice-poor period. Figure 5 shows the fluctuations of the mean position of the ice edge for these two periods. In the ice-rich period, the ice belt between 65°N and 70°N had a mean width of approximately 175 km (95 nautical miles) and thus, on the average, it was 65 km (35 nautical miles) wider than in the ice-poor period, when its mean expansion reached only a mean width of 110 km (60 nautical miles). The corresponding extreme values of the years 1952 and 1957, namely 200 km (110 nautical miles) and 80 km (45 nautical miles), respectively, give a difference in width of 120 km (65 nautical miles).

It should be emphasized that, due to the abovementioned limitations of the observation material, the indicated values are intended only as a very general measure of the ice transport of the East Greenland Current. Isolated deviations are definitely possible; however, the classification of the yearly values for an ice-rich or ice-poor period would certainly correspond to the actual situations.

3. THE OCCURRENCE OF WIND GENERATED ICE DRIFT IN THE ARCTIC OCEAN AND ITS RELATIONSHIP TO THE ICE TRANSPORT OF THE EAST GREENLAND CURRENT. The ice drift in the Arctic Ocean is largely wind generated. The current generated components assume a dominating role only in the approach to the out-flow area between Greenland and Spitzbergen.

According to the rule formulated by N.N. Zubov, the pack ice in those areas of the Arctic Ocean that are far from land will drift approximately in parallel with the isobars. Thereby, the area with high air pressure is to

*) "Dänemarkstrasse", terminology according to Weltkarte, Namen und nautische Grenzen der Ozeane und Meere [World map, names, and nautical borders of the oceans and seas], S.Dt.Hydrogr.Z., Vol. 20, 1967, p. 22. The Editors.

**) At the time of the completion of the investigation, the 1959 yearbook was not yet published.

the right of the drift direction, and the speed of the drift is proportional to the air pressure gradients. – Thus, the air pressure difference between the terminal points of a profile line may be used as a measure for the main direction and the intensity of the wind generated ice drift along this profile.

Considering the reasoning presented in the introduction, the following two profile lines were selected for defining the wind generated ice drift in their areas (See Figure 1):

Profile A (P_A): On the 180th meridian, between 85°N and 75°N. The profile is approximately parallel with the border area between the Pacific Gyral and the Transpolar Drift Current. For purposes of this investigation, it is assumed that the exchange drift between the two drift systems occurs mainly in this area.

Profile B (P_B): At 80°E between the North Pole and 80°N. The profile is almost vertical to the Transpolar Drift Current and should include the main direction and the intensity of the wind generated ice drift within its area.

The air pressure differences between the terminal points of the individual profiles were identified in such a manner that the value of the southern terminal point was subtracted from that of the northern one in each case. Then, positive air pressure differences indicate a wind generated ice drift from the Pacific Gyral via P_A to the Transpolar Drift Current or via P_B in the direction of the Transpolar Drift Current, while negative air pressure differences indicate correspondingly opposite drift directions.

The time correlation of the annual values of air pressure differences between the terminal points of the profile lines P_A and P_B with those of the ice transport of the East Greenland Current was performed on the basis of known data concerning the duration of the drift of polar pack ice into the region of the Denmark Strait and with consideration of the intensity of the wind generated ice drift in the Transpolar Drift Current. The mean drift rates of 2-3/4 years for P_A and 1 year for P_B were correspondingly adjusted. While the annual values for P_B represent true annual means from the values for the summer half-year (SH = April - September) and the winter half-year (WH = October - March), overlapping means from the values of four subsequent half-years were calculated due to the long drift duration for P_A; thereby, the two middle values were counted twice in each case*).

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*) In detail, the following time correlations were used:

Ice transport in the East Greenland Current	Mean value of air pressure differences between the terminal point of profile lines: P_A	P_B
1949	SH 1946 - WH 1947/48	SH 1948 - WH 1948/49
50	SH 1947 - WH 1948/49	SH 1949 - WH 1949/50
51	SH 1948 - WH 1949/50	SH 1950 - WH 1950/51
52	WH 1949/50 - SH 1951	SH 1951 - WH 1951/52
1957	WH 1952/53 - SH 1954	WH 1955/56 - SH 1956
58	WH 1953/54 - SH 1955	WH 1956/57 - SH 1957
60	SH 1956 - WH 1957/58	WH 1958/59 - SH 1959
61	SH 1957 - WH 1958/59	WH 1959/60 - SH 1960

The results can be interpreted as follows. The long term mean value for P_A of 0.015 mb/100 km indicates that there are practically no decreases in the air pressure between the terminal points of this profile. Apparent y, the profile is actually located in the border region of the two drift system, and in such a manner that the ice drift generally is parallel to it. On the other hand, one can assume a wind generated ice drift over the profile in the direction of the Transpolar Drift Current, judging from the long-term mean value for P_B of 0.380 mb/100 km.

Figure 6 shows the deviations of the 8 annual values from the corresponding 8-year means of the ice transport in the East Greenland Current as well as for the air pressure differences for corresponding periods between the terminal points of the profile lines P_A and P_B. The 8-year means for ice surface and P_A of 157,500 km^2 and 0.010 mb/100 km coincide, practically, with the previously mentioned long-term means, while the 8-year mean for P_B of 0.330 mb/100 km has, by comparison, a value that is 0.050 mb/100 km lower. From this diagram, the following general statements can be concluded.

1. The ice-rich period in the East Greenland Current apparently corresponded to a previous influx of ice from the Pacific Gyral via P_A into the Transpolar Drift Current as well as with an increased development of the Trampolar Drift Current itself.

2. Apparently, the opposite type of drift conditions in the Arctic Ocean determired the ice-poor period in the East Greenland Current: it corresponded to an outflow of ice from the Transpolar Drift Current via P_A into the Pacific Gyral as well as with a decreasing development in the Transpolar Drift Current itself.

It was not to be expected that the presented three curves would be correlated in all details or run parallel in all respects, since this investigation included only one part of a complex causal network. Nevertheless, there is a far-reaching correlation e.g. in the classification of the extreme values and - with one exception, P_A (1957/58) - the corresponding deviations in the three magnitudes are of the same nature. The interpretation of the diagram can be concluded with the suggestion that prior to the extremely decreased ice expanse in 1957, the wind generated ice drift in the Transpolar Drift Current via P_B in the corresponding time period 1955/56 must have been not only considerably weakened but also on the average going in the opposite direction.

4. MAJOR TYPES OF ATMOSPHERIC CIRCULATION OVER THE ARCTIC OCEAN AND THEIR EFFECT ON THE ICE DRIFT. Initially, the relationships between the applicable locations of the baric circulation center and the development of the ice drift in the Arctic Ocean were briefly mentioned. In a brief analysis of the atmospheric circulation it will therefore be attempted to elucidate these relationships to some extent. For this purpose, and considering the location of the specific air pressure field in relation to the ice drift pattern, a differentiation is made between five major types of atmospheric circulation and their relative frequency will be determined in relation to the ice-rich and ice-poor periods which each have a duration of four years.

The "high over the Pacific Gyral", H(PW) (See Figure 7) represents ideal conditions for the development of the ice drift patterns, i.e. with this pressure distribution, there is no wind generated exchange of ice between the two drift systems. In respect to the ice-rich period, this circulation type is about 3-4% more common than for the ice-poor periods. (For a duration of four years, a 1% frequency corresponds to approximately 15 days.)

Circulation types with the opposite effect on the development of the ice drift are shown in Figure 8; namely the "central high pressure location", H(Z), and the "central low pressure location", T(Z). The former causes a wind generated ice drift from the Pacific Gyral via P_A to the Transpolar Drift Current as well as further in the direction thereof; the central low pressure location will cause opposite drift directions. The differences in frequency between these two circulation types in reference to the ice-rich and ice-poor periods would confirm the indicated relationships with the ice transport in the East Greenland Current. Thus, the ice-rich years corresponded with the maximum of H(Z) and the minimum of T(A), while the opposite relationships dominated in respect to the ice-poor years. For instance, the frequency of H(Z) in the ice-rich period, 35%, is approximately twice that of T(Z), which almost doubled its frequency during the ice-poor period.

The last two circulation types are to be regarded as mixed types, since their influences on the ice drift are not unequivocal (See Figure 9). Although the "low above Barents Sea and Kara Sea", T(Ba), occurs on 1/5 of all days and thus could be characterized as a significant causal force for the Atlantic part of the Transpolar Drift Current, ice is nevertheless transported via P_A from the source region of the Transpolar Drift Current to the Pacific Gyral due to the high pressure forced aside over the Chukchi Sea; this results in a decrease of the ice transport of the Transpolar Drift Current. In case of a "low over the north-east Siberian shelf seas", T(nS), the ice drift behaves in the opposite manner: ice from the Pacific Gyral arrives in the source region of the Transpolar Drift Current; however, the wind generated drift in its region is largely of the opposite direction.

5. CONCLUSIONS. Table 1 summarizes the individual results. The investigation of the ice transport of the East Greenland Current showed that in the period from 1931 to 1961, the years 1949-52 can be characterized as ice-rich, the years 1957-58 and 1960-61 as ice-poor. In the months of April - August, the mean expansion of the ice between 65°N and 70°N amounted to 194,000 km^2 and 121,000 km^2, respectively. The air pressure differences between the terminal points of the profiles P_A and P_B can be used as a measure for the development of the wind generated ice drift in the corresponding areas of the Arctic Ocean. The values for P_A and P_B can be interpreted to mean that, corresponding to the ice-rich period, an influx of ice from the Pacific Gyral via P_A has apparently increased the ice transport of the reinforced Transpolar Drift Current prior to its reaching East Greenland. On the other hand, the ice-poor years in the East Greenland Current would have been preceded by a weakening of the Transpolar Drift Current as well as a decrease of its ice transport due to out-flow of ice from its source region via P_A into the Pacific Gyral. In respect to the development of the Transpolar Drift Current in relation to the ice-rich and ice-poor periods, a ratio of 3.4:1 is obtained from the two corresponding means of the air pressure difference between the terminal points of the Profile P_B, 0.515 and 0.150 mb/100 km.

Probably, a vast change in the atmospheric circulation over the Arctic Ocean is of importance as a reason for the variations in the ice transport of the East Greenland Current during the two time periods investigated, whereby the directly contributing element was the development of the wind generated ice drift. In the late 40's and the early 50's, high air pressure dominated over the central Arctic Ocean, and the great number of circulation types contributing to the

Table 1

Mean values of the ice expanse in the East Greenland Current between 65°N and 70°N (April - August) for the ice-rich (1949-52) and ice-poor periods (1957-58, 1960-61), corresponding amounts of air pressure differences over P_A and P_B, and the frequency of conforming and diametric circulation types

	Ice-rich Period (1949-52)	Ice-Poor Period (1957-58, 1960-61)
Ice surface	194,000 km^2	121,000 km^2
Pressure difference		
1. over P_A	0.090 mb/100 km	- 0.075 mb/100 km
2. over P_B	0.515 mb/100 km	0.150 mb/100 km
Frequency of the circulation types		
1. referred to P_A	(SH 1947-WH 1950/51)	(WH 1953/54-SH 1955, WH 1956/57-SH 1958)
a) conforming [H(z), T(nS)]	48.0%	40.5%
b) diametric [T(z), T(Ba)]	38.5%	50.5%
2. Referred to P_B	(SH 1948-WH 1951/52)	(WH 1955/56-SH 1957, WH 1958/59-SH 1960)
a) conforming [H(z), H(PW), T(Ba)]	70.5%	55.0%
b) diametric [T(z), T(nS)]	29.5%	45.0%

general direction of the outflow reinforced the ice export from the Pacific Gyral into the Transpolar Drift Current as well as from the Arctic Ocean into the Greenland Sea. In the second half of the 1950's, however, an increased number of central low pressure locations as well as a more frequent overlapping of the north Siberian anticyclone on the north-east Siberian shelf seas (including the Chukchi Sea) weakened the air pressure decreases towards the adjoining land masses, even reversed them in the area of the Bering Strait. The result was a decreased outflow of ice from the Arctic Ocean into the Greenland Sea.

The results of the investigation indicate that consideration of the initial reasoning can be useful for a long-range prognosis of the ice transport in the East Greenland Current. However, a limiting remark should be made to the effect that for the time being, it is only possible to make a very general characterization of the ice conditions, since the expansion of the ice belt in the East Greenland waters is modified in its details by local factors. Further, the the indicated relationships will be less clear as the atmospheric circulation over the Arctic Ocean retains permanent tendencies for shorter periods of time.

In respect to this year (1968), the Transpolar Drift Current is probably stronger developed*). Furthermore, a P_A value of 0.155 mb/100 km would lead

*) The mean air pressure difference between the terminal points of P_B was 0.450 mb/100 km for the period from September, 1967, to March, 1968.

**) Mean value for the air pressure difference for the period WH 1964/65 - SH 1966.

to the assumption that a strong additional flow of ice from the Pacific Gyral has increased its ice transport. Both criteria point to an ice-rich season 1968 in the East Greenland waters. Satellite photos from late March/early April, which make it possible to recognize an unusually wide ice belt between Iceland and Jan Mayen, seem to support this assumption (See Figure 3 c).

The subsequent evaluation of the images from the weather satellite "ESSA 6" of the ice transport of the East Greenland Current showed (K. Strübing [1968]) that in April of 1968, the ice belt between 66°N and 72°N of 410,000 km^2 reached a mean expansion which exceeded the corresponding long-term average by 140,000 km^2.

The satellite photos were made available by the courtesy of the National Environmental Satellite Center, Suiteland, MD, USA (Figures 3 a and 3 b) and by the Institut für Meteorologie und Geophysik der Freien Universität Berlin [Institute of Meteorology and Geophysics of the Free University of Berlin], Department of Meteorological Satellite Research [Abteilung Meteorologische Satellitenforschung] (Figures 3 c and 3 d).

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